

even considerably more than on the current rainfall. We are not bothered much with sandstorms when the rainfall is normal or above and reasonably well distributed (some exceptions, however), while we occasionally have rather severe sand or dust storms a few hours after a heavy local rain.

The extent of the sandstorm is probably about the same as the extent of the high winds and the bare ground. I have personally seen much worse sandstorms on the plains of Texas, around Plainview, than I have seen in this vicinity; and Abilene people, who have occasion to be in El Paso at the same time that we have a sandstorm in this vicinity, occasionally come back and report that "New Mexico and Arizona both passed through El Paso the day before."

The visibility in a sandstorm varies, of course, with the intensity: In extreme cases it is perhaps not over 100 feet for a few minutes at a time, 300 feet for 30 minutes to an hour, not much over a quarter mile for 2 or 3 hours, and perhaps one-half mile for 4 or 5 hours. The most severe sandstorms occur in the day time, and are sometimes rather severe from about 9 or 10 a. m. to about 7 or 8 p. m.

Most of the sandstorms occur during February, March, and April, these months usually being comparatively dry, until after the middle of April, and the ground usually being bare or almost so, especially that in cultivation, until about the 1st of May, except an occasional year when considerable small grain is planted.

The Big Spring sandstorm bears a striking resemblance, as was pointed out by Prof. A. J. Henry, to the haboobs of the Egyptian Sudan, a photograph of which was reproduced in the Quarterly Journal of the Royal Meteorological Society January, 1925, with an account by L. J. Sutton. Sutton states that the haboob is a dense mass of whirling sand usually accompanied by a strong wind, but he does not clearly distinguish it from other sandstorms. Col. H. G. Lyons, commenting on Sutton's paper, suggests the similarity between haboobs and line-squalls. The haboobs he had experienced appeared as a front of violent upward and downward currents, in which the most striking feature was a mass of dust often thick enough to cause extreme darkness. Lyons thought the term should not include very strong dust-carrying storm, but be limited to circular storms which occur during periods of atmospheric instability. Haboobs in Nubia, he observes, usually come from the southeast and as they pass the wind veers round quickly to northwest, the sky clears and it is definitely colder.

Similar conditions have been noted by pilots in west Texas; shortly after the worst of a sandstorm had passed a cold layer of air near the ground was found to be overrun by a warm layer at about a thousand feet. It appears, therefore, that there is more than a superficial resemblance between the haboob and the Big Spring storm.

THE FOREST FIRE-WEATHER SERVICE IN THE LAKE STATES

By J. R. LLOYD¹

[Weather Bureau, Chicago, Ill.]

It is doubtful if the average person grasps the enormity of the waste that has been, and is still being caused, in our great forests, which form a large portion of our northern woodlands. In order to acquire a true conception of the situation it is necessary for one to travel through the forests, noting the extent of the areas burned over and the damage that has been done, and to study forest fire statistics.

While no fires of really great extent have occurred in the Lake States in late years, the great Minnesota fire of October 12, 1918, stands out as an example of what might happen again if it were not for the eternal vigilance of the fire protection organizations; and there are times, when weather conditions go against them, that they are almost helpless. This great conflagration was the result of several factors operating in unison. The summer of 1918 in Minnesota was dry and warm, causing the grasses and other small vegetation on the forest floor to dry out and die much earlier than usual. This was followed by a dry autumn, which increased the fire hazard tremendously. Minnesota has much swamp land, and most of the swamps are filled with peat. There are more than 5,000,000 acres of peat land in Minnesota, of which a large portion had been drained prior to 1918.

Therefore, when the drouth of that year developed these peat lands dried out and became the chief source of trouble. Fire in peat is exceedingly difficult to extinguish. Some peat fires have been known to burn from one summer to another, even under a heavy covering of snow during the intervening winter. It so happened in 1918 that the State Forest Service of Minnesota lacked sufficient funds to meet this emergency, due largely to political dissension among State officials and legislators. This was exceedingly unfortunate. Many small fires

were started in the peat lands that were not extinguished because of this lack of funds and personnel. These fires smoldered along until there came a day, October 12, with clear sky, low relative humidity, mild temperature and, fresh southwest winds. Then these smoldering fires spread, picked up momentum, merged into one great fire—the greatest of record in this country—and swept on, destroying nearly every living thing in its path. It traveled at great speed, and created winds powerful enough to pull up by the roots large trees. It swept over nearly a million acres in one afternoon and the early part of the following night, snuffed out the lives of nearly 1,000 human beings, killed thousands of domestic and game animals and birds, and destroyed probably \$75,000,000 worth of forests and property. The city of Duluth had a very narrow escape, being saved principally by a high range of hills in the rear that parallel the shores of the lake and the bay. This great conflagration is mentioned as an example of what can happen in the northern woodlands when weather conditions are just right.

Since weather conditions play a major rôle in forest fire protection and suppression, it therefore follows that if the forest protective organizations know what to expect in weather for even a day or two in advance that they will be in a position to act on a given situation to better advantage. Therefore, the fire-weather service in the Lake States was created to supply a demand, voiced by the fire protection organizations, for weather forecasts and other weather information that might help them in combatting this red scourge that has cost so many millions of dollars in money, and taken so many thousands of lives of human beings and denizens of the wild.

The project was started in Minnesota during the summer of 1926. From a modest beginning in 1926 the service has been gradually expanded. It was organized in Wis-

¹ In charge fire-weather project in the Lake States.

consin and upper Michigan in 1927 and 1928, and in lower Michigan in 1928. It now covers all of the principal forested lands in the three States, embracing nearly 60,000,000 acres. There are now 33 substations scattered throughout the fire-weather district. These substations are the eyes of the service, so to speak. Most of them are located at the headquarters offices of the State district rangers and wardens, and are about 40 to 60 miles apart from each other. Each station is equipped with a maximum and a minimum thermometer, a rain gage, a sling psychrometer, and an anemometer, and some of them are supplied with hygrographs. Observations are made three times a day, at 8 a. m., noon, and 5 p. m., central standard time, and are usually begun about the 1st of April and continued until about the 31st of October. The headquarters of the service is now located at Chicago, having been transferred from Duluth, Minn., on November 1, 1928.

During the fire season about 25 selected fire-weather stations telegraph reports to Chicago once a day, immediately following the 8 a. m. observation. These reports show what kind of weather has prevailed during the 24-hour period ending at 8 a. m., and give an estimate made by the observer of the degree of fire hazard existing in the forest in the vicinity of the station. The data from these reports are entered on a special outline map, and give a good birds-eye view of conditions existing throughout the district. Particular attention is given to the relative humidity, in connection with the temperature, sunshine, wind movement and rainfall. All these elements are factors in evaporation, and consequently in fire hazard. It may be readily seen that estimation of the degree of fire hazard existing at a given time, and an estimate of what it will be one or two days in advance is a very complicated problem. Not only do the weather factors have to be considered, but thought has to be given to the condition of the forest fuels, which are gradually changing throughout the season, and which are many and variable in kind and character. No single instrument has yet been devised that will give a reliable estimate of the degree of existing hazard. The duff hygrometer, an instrument devised to measure the moisture content of duff and litter on the forest floor has not proved to be successful. The evaporimeter does not give a good index either, since the evaporation that is measured by it is produced in an artificial manner that is not comparable to the manner in which evaporation takes place from forest fuels. Therefore, estimation of existing hazard is largely a matter of personal judgment formed after considering all of the factors involved, and opinions may vary considerably between two or more individuals on a given condition.

When the daily fire-weather reports are received and entered on the map and it is indicated that fire-weather warnings are in order, warnings are made and dispatched to the men in the field as soon as possible, usually about 9.30 a. m. A typical warning as issued for the field would read about as follows:

Fair Friday and probably Saturday; temperature near 90°; humidity 25 to 35 per cent; gentle to moderate southerly winds becoming southwest by Saturday; high to extreme hazard.

Warnings are telegraphed to sections only where the fire hazard so warrants, and as a rule, the State district rangers and wardens, the superintendents of the State forests, and the supervisors of the national forests are the persons that receive them. Warnings are telegraphed to about 55 points scattered throughout the forested area. The men that receive these warnings by telegraph relay them by telephone to their principal assistants in the field, so that all of the men that have charge of fire pro-

tection and suppression work are supplied with this information. The warnings also are broadcast by radio from several stations in or near the forested regions, and are printed in several newspapers as well.

Although particular attention has been given to relative humidity in determining fire hazard, it is doubtful if relative humidity is a more important factor in this connection than temperature. It seems that pioneers in fire-weather investigation, even up to the present time, have overstressed the importance of relative humidity in proportion to temperature in estimating fire hazard. The writer has recently performed some research work in this connection to determine the relationship of relative humidity and temperature to the inception of forest fires. This investigation disclosed the fact that relative humidity and temperature bear practically equal weight on fire hazard, and that these two factors are embodied in the depression of the wet-bulb thermometer of a whirled psychrometer in such a manner that the fire hazard seems to be directly proportional to the change in the wet-bulb depression, other factors being equal. This throws into discard the theory that fire hazard is proportional to the change in depression of the dew point, an idea that seemed to be substantiated by preliminary investigation.

Inception of forest fires, when plotted on a graph against relative humidity, temperature and depression of the wet bulb, have a well defined range. Out of 2,000 fires plotted it was found that only one fire started with temperature below 39°, and that none started when the relative humidity was above 80 per cent. It is also a fact that not a single fire broke out when the wet-bulb depression was below 4°, and that all the fires had started by the time a wet-bulb depression of 26° was reached. The investigation indicated that the wet-bulb depression scale may be divided arbitrarily into rather definite zones of hazard. However, these zones of hazard, being predicated on average conditions, would naturally not apply all of the time. Higher than ordinary wind velocities and periods of drouth would tend to augment the hazard, while on the other hand, appreciable rainfall would tend to lower it, resulting in a shifting of the zones to higher and lower positions on the wet-bulb depression scale.

The fire-weather forecasts are based largely upon the daily manuscript weather maps and the auxiliary pressure change and temperature change charts. There are several types of weather maps that may give rise to high fire hazard, but the most striking type is the one with a HIGH centered west or northwest of the fire-weather district and moving southeastward, followed by a LOW that moves eastward along the Canadian boundary or a little to the northward thereof. This type of map usually gives the lowest relative humidity, and is quite common in spring, April and May, when usually the lowest relative humidity readings occur. The relative humidity usually runs low within the confines of these HIGHS as they pass over the fire-weather district, and when they move in such a manner as to place the center of the HIGHS over the middle Mississippi and the Ohio valleys during the daytime, they often produce extremely low relative humidity readings on the days when such circumstances occur. Relative humidity readings as low as 11 per cent have been noted in May in Minnesota, and readings in the twenties are not at all uncommon in all three States under such conditions. These low relative humidity values are undoubtedly brought about by pressure conditions that allow rapid night radiation of temperature, followed the next day by a rapid rise, thus producing a great range in temperature during the day, and consequently unusually low relative

humidity. Diurnal ranges in temperature of 45° to 50° have been noted in the forested areas of the north when favorable pressure distribution prevails.

As a rule, more forest fires occur in the spring than during any other season of the year, due to the fact that there is then a plentiful supply of dead vegetation on the ground; the days are long, allowing much sunshine; the deciduous trees are leafless or nearly so, allowing the sunshine to strike the forest fuels and dry them out quickly; the relative humidity is at its lowest; and finally, there is usually plenty of wind movement to help dry out the fuels and fan the flames, once a fire is started. However, the year of 1930 proved an exception to the rule in this respect. The long, hot drouth in August and September caused an unusually severe summer fire season that was much more severe than the preceding spring fire season. Michigan and Wisconsin experienced this year one of the worst summer fire seasons, if not the worst, in the history of their respective forest services. The fall fire season is short, as a rule, due to the fact that the days are short and the nights are cold. The relative humidity may be low during the middle of the day in autumn, but only for a few hours, and it is nearly always high then at night, which, with the low night temperatures, is sufficient to either extinguish most ordinary fires, or to check them to such an extent that they may be easily extinguished. The forest rangers say that a cold night is worth the services

of 100 or more men in putting out a big fire. While the fall fire season is short and usually less severe than the spring season, it is a singular fact that most of the great conflagrations of the north have occurred in autumn. However, these great fires have always followed drouthy summers.

Fire protection in the Lake States is a problem that has to do largely with care exercised by man; therefore, to a large degree, it is an educational problem. Ninety-nine per cent of all forest fires that occur in the Lake States are man-caused, either directly or indirectly. The other one per cent is caused by lightning. There are areas in the Western States where 35 to 50 per cent of the fires are caused by lightning, thereby creating a very difficult problem; but the number of lightning fires in the Lake States is so small that lightning is given no consideration in the forecasts. The number of fires that occur in the Lake States annually is very large, but of course varies considerably from year to year, depending on the weather. During 1929 about 6,500 fires occurred in these States, burning over about 450,000 acres. This year's totals are not yet available, but it appears that there were probably as many as 7,500 fires that burned over more than a half million acres. Such is the heavy toll exacted by fire, man's greatest friend, it has been said, but perhaps at the same time his greatest enemy.

AIRPLANE LANDINGS IN GUSTY SURFACE WINDS

By PAUL A. MILLER

[Weather Bureau Airport Station, Bolling Field, D. C.]

When surface winds are moving at velocities over 25 miles per hour considerable difficulty is often encountered in landing an airplane. During such times the air currents moving along the surface are considerably retarded by friction, while a few feet above the surface the flow is unhindered. This results in a turbulent condition near the surface, which makes a treacherous landing support for an airfoil passing through it, especially if the wind is gusty.

An airplane landing in still air is glided down within about 2 feet of the ground, where it is leveled off. Flying along level with the motor cut off, it soon loses speed and support. However, it is kept from falling by gradually raising the nose, which presents the airfoil surfaces, at a larger and larger angle to the air, with consequent very gradually decreasing support, but rapidly lessening speed. Presently the speed is so low that the airfoils, no matter what their angle, can no longer fully support the plane, and it settles slowly to the ground in a 3-point landing, i. e., the wheels and the tailskid touch at the same instant. During this time, since the air is still, it has not been necessary to correct for the lateral or longitudinal position of the plane.

How different the case where a strong, gusty surface wind is present. Long experience then becomes necessary to make a good landing, for the plane is buffeted, raised, or dropped unceasingly, and the pilot must have the delicate touch and feel to anticipate and overcome the hazards before they place the plane in a perilous position. If the plane is kept in the proper position to make a landing in still air, the landing will be extremely hazardous. For, if the plane is glided down at normal speed, it will encounter gusts and vertical currents which will raise it, drop it, or throw it over on one wing. Also when leveling off to land, the pilot does not dare to lose much flying speed, for he must have positive control to overcome gusts,

and this can be maintained only with an excess of flying speed. For instance, an ordinary mail plane, well loaded, usually lands with an air speed of about 55 miles per hour. Now, if a 30-mile wind is blowing, the plane will land with a ground speed of about 25 miles per hour. Let us assume that the pilot intends to land in the manner used in still air and that he is leveled off and just ready to touch the surface. A sudden gust raises the wind velocity temporarily to 40 miles per hour, giving the plane an actual air speed of 65 miles per hour, and at the large angle the airfoils now present, the plane will suddenly be lifted to a height of 10 or 15 feet. The gust passes, leaving the plane stalled, as the gust has also taken a part of the plane's forward speed. Now, if the pilot has not quickly speeded up the engine and put the nose down in order to gain air speed the plane will actually fall to the ground, with considerable damage to it and a bad shaking up or worse for the pilot. Complicate this situation during landing with the fact that there may be rather violent vertical currents present, which will throw the plane over on one wing or raise or drop it suddenly, and it will readily be seen that under conditions of gusty winds a landing can not be made in the normal manner with any degree of assurance.

Under such conditions, most pilots of experience bring the plane in with an excess of flying speed, probably 10 or 15 miles per hour over the normal speed. Then if the plane is thrown into an abnormal position, the controls have a quick action and the plane can be righted quickly. However, with this excess of flying speed, the plane will not settle to the ground, but must actually be flown down until the wheels touch the surface, it being understood, of course, that the excess speed is gained by nosing down at a steeper angle than normally rather than by the use of the engine. When the wheels touch, the tail is kept up in flying position, which causes the airfoils to present a small